Advanced Electrical Power Systems Technical Overview 6.2 Program Review Nov. 5-7, 2002

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Long Term Vision

- Ultimate Extrapolation of Present Design Methods
  - Future Power Systems will be designed and characterized completely on computer.
- Ultimate Extrapolation of Power Integration
  - Capacitors, inductors, conductors, power switches, and heat sinks, and etc. integrated into a multi-layer, multi-material, 3 dimensional, solid power-processor block
- Ultimate Extrapolation Electrical System Control
  - control of all conversion (electrical, mechanical, thermal, chemical, and etc.) loops and time frames from one common control bus -- access to any time frame from anywhere in the system via a control hierarchy formed logically not physically.
- Ultimate Extrapolation of Electrical Reconfiguation –
  - Creation energy conversion functions from the synergistic energy conversion of an entire system (for example create active filtering and energy storage anywhere in the electrical system and at any time)
  - Creation of electromagnetic and electrostatic forces from the synergistic energy conversion of an entire system

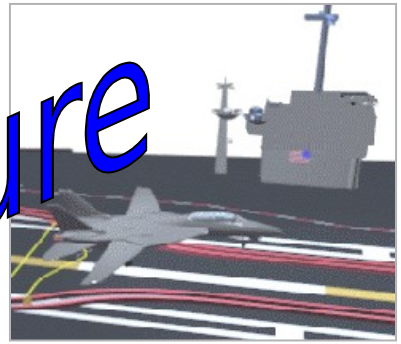
Advanced Electric Power Systems Thrust

Transforming the Military

Hybrid Electric TTD

Advanced Hybrid Electric Drive Technology Program (8X8)

Electromagnetic Arrest and Launch



Reconnaissance, Surveillance, Targeting Vehicle (RSTV),

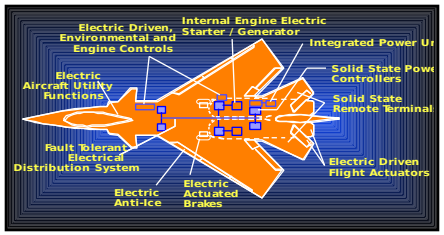
Future

Legacy

UCAV

JSF

ALL-ELECTRIC SHIPS

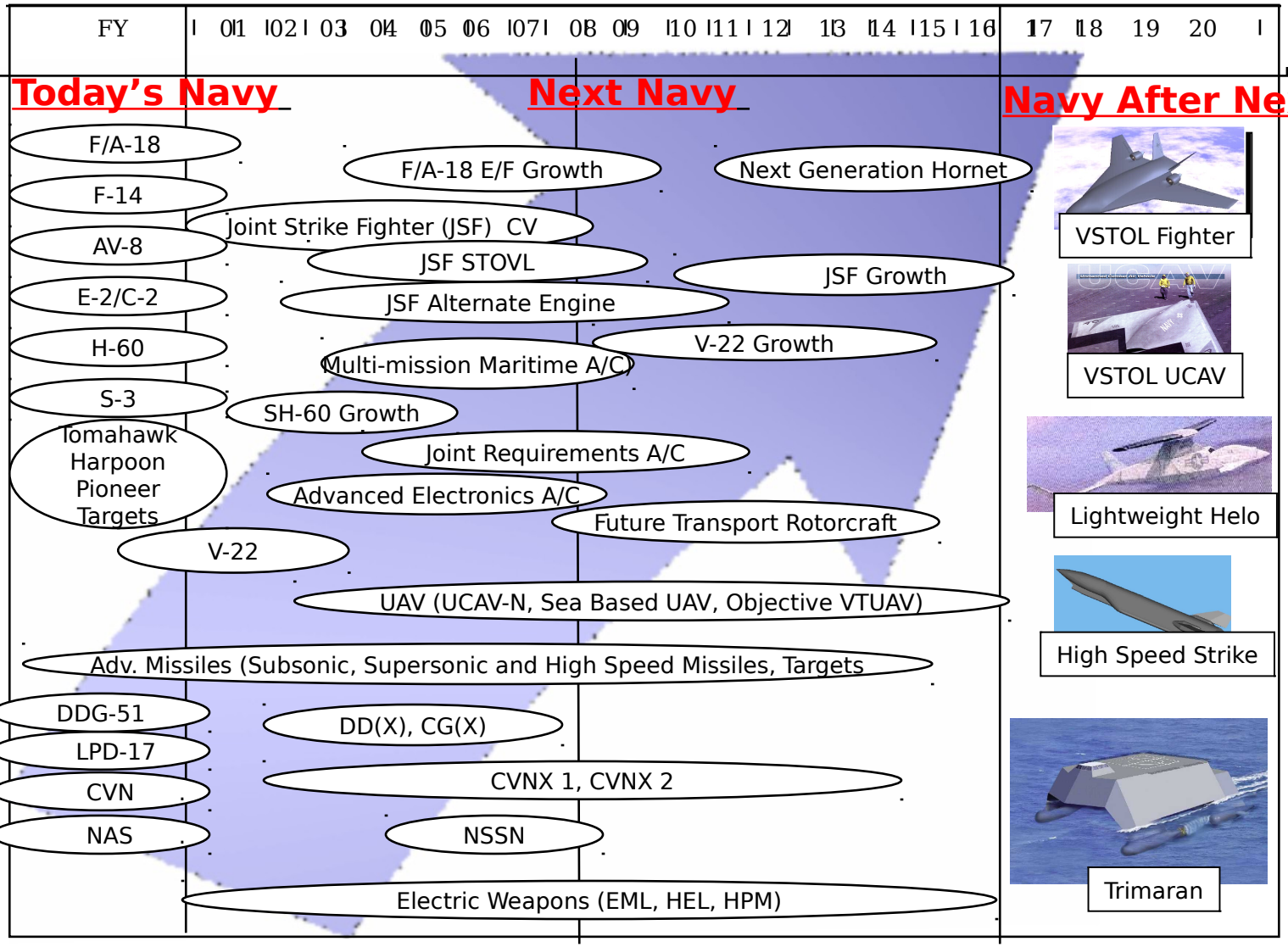

Electric Driven, Environmental and Engine Controls
Internal Engine Electric Starter / Generator
Integrated Power U
Solid State Powe Controllers
Solid State Remote Terminal
Electric Aircraft Utility Functions
Fault Tolerant Electrical Distribution System
Electric Driven Flight Actuators
Electric Anti-Ice
Electric Actuated Brakes

MORE ELECTRIC AIRCRAFT

***TACTICAL* DIRECTED ENERGY WEAPONS**

Every DoD Platform has a Power System

Advanced Electric Power Systems Thrust



Advanced Electric Power Systems Thrust

ONR Electrical Thrusts - Relationships

Why Electric Power?

- **Common generation**
  - **A common energy source for propulsion & ship service power**
- **Total ship energy management & control (reconfigurable)**
  - **Electrical energy can be rapidly & efficiently re-directed throughout the distribution system rather than exercising power control over a moving mass**
- **Energy allocation adaptable to mission needs**
  - **Ability to instantaneously service peaks or valleys in demand according to mission priority**
    - **Without incorporating large excess capacity**
    - **Without suffering excessive energy dissipation**
  - **Ability to alter functions, bandwidth, and distribution in situ**

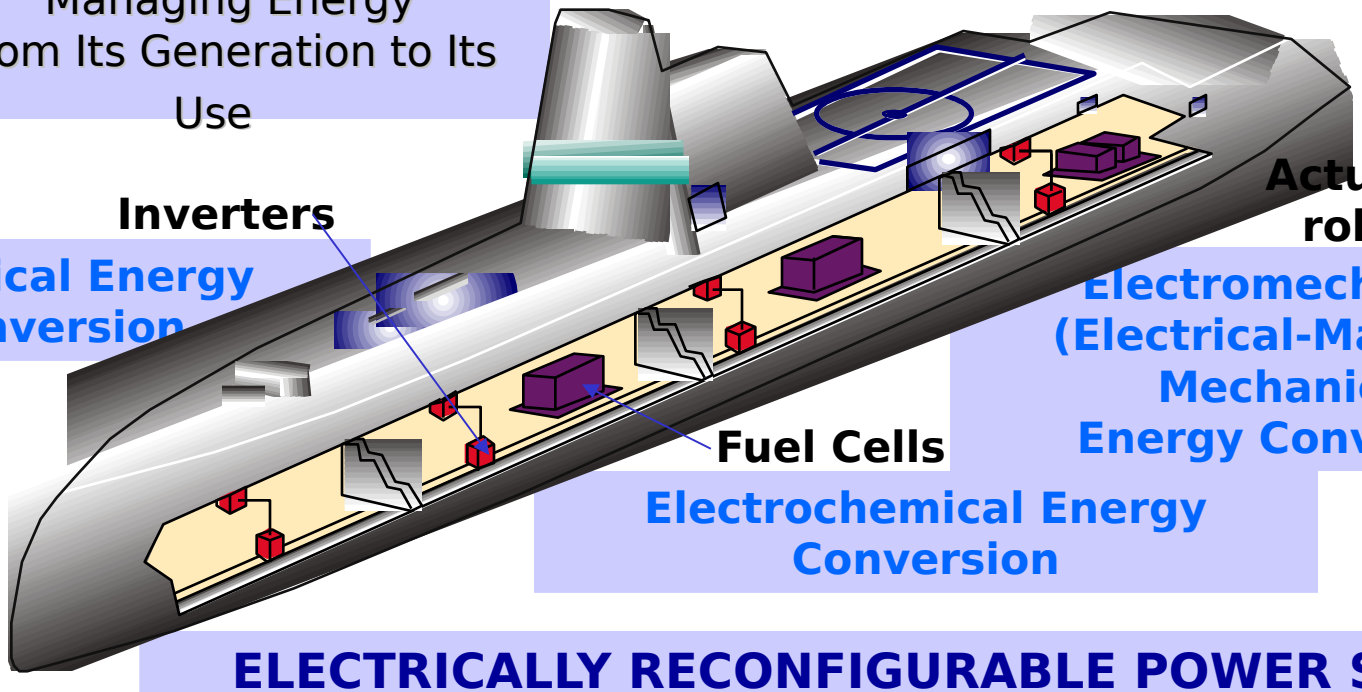
Enabled by advanced solid state power control & conversion technology

"Power Electronics"

Why Electrically Reconfigurable Ship?

Advanced Electric Power Systems Thrust

Managing Energy from Its Generation to Its Use



ELECTRICALLY RECONFIGURABLE POWER SYSTEM ENABLES

- ⇧ **More Surviv**
- ⇧ **Integrated Ship Control, C⁴I, Engineering Plant, & Damage Control Systems**
- ⇧ **Leverage of commercial technology & continuously upgraded modular architectures (hardware & software)**
- ⇧ **Near Zero Emission of NOX, SOX, … Pollutants**

Relationship to Other Sponsored Activities

- Services / Defense Agencies / Other Government Agencies / Industrial Investments
  - Army, Air Force, DARPA, DOE
- International efforts
  - Cambridge University & MOD, UK (VTB and MOD funded)
  - Taganrog St University, Russia (VTB funded)
  - ABB, Switzerland (cooperative agreement)
  - Collaborations – See next slide

Navy Science & Technology Challenges

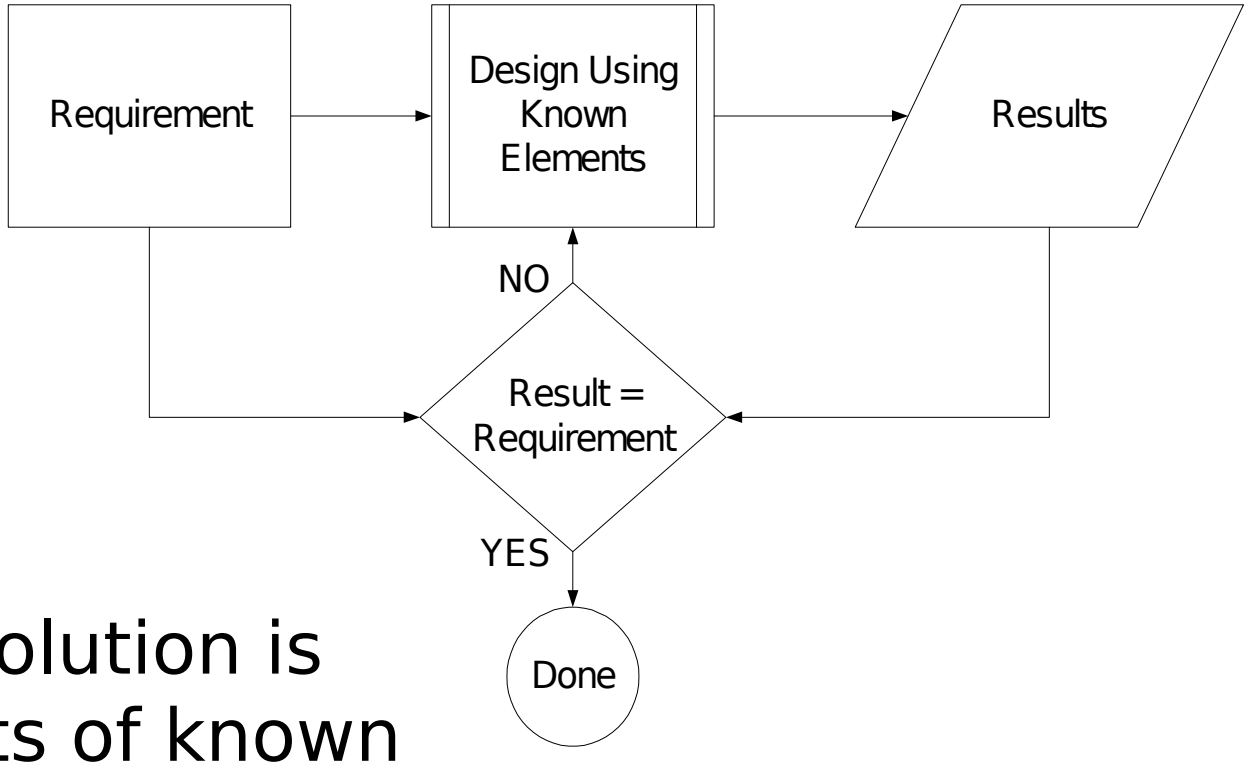
- **Integrated engineering, propulsion & combat system resource management & control – (“Multi-Physics Based Modeling and Simulation”)**
- **Reconfigurable, uninterruptible electrical power systems**
- **Reconfigurable auxiliary machinery systems**
- **Affordable manning via automated damage control, watchstanding functions (remote situational awareness), & stores and ordnance management**
- **Signature management via HM&E systems tuning**

Navy Systems Science & Technology Issues

- **Self-organization of systems of complex systems -- >10k State variables**
- **Cellular & Hierarchical design for Open Plug & Play Architecture & System Operation**
- **Simulation and control extending over >6 orders of magnitude in time**
- **Physics based analysis tools and models for non-linear circuits and loads and highly coupled power systems, "Multi-Physics based modeling and simulation."**

Engineering

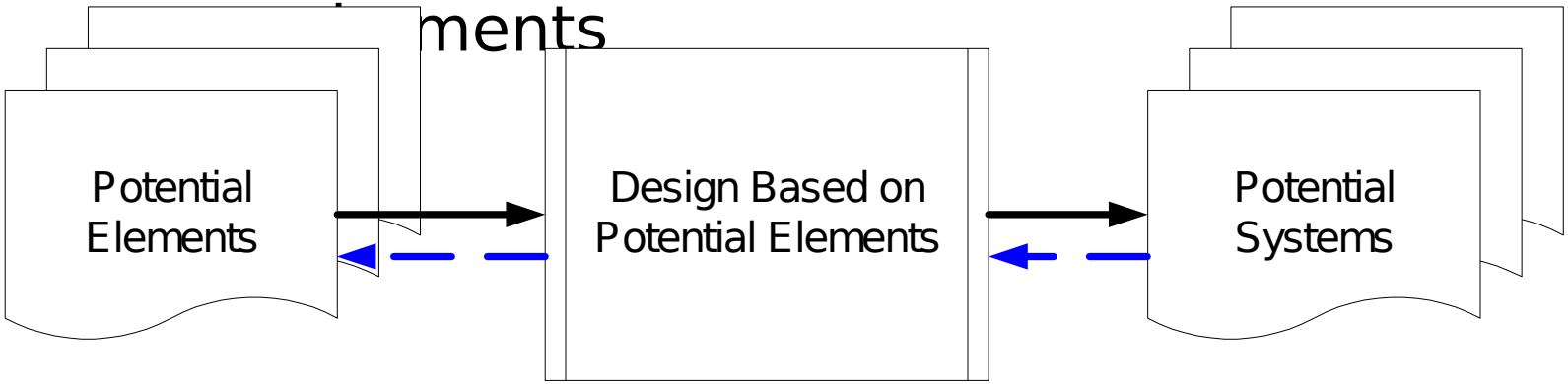
- Design Base on Known Elements
  - Requirement
  - Result
  - Iteration



- Requirement solution is within the limits of known elements
- Process of Interpolation

Engineering Science

- Study (Design) based on potential elements
  - Potential elements
  - Set of potential system designs
  - Set of potential future requirements
  - **Extrapolation** from known elements, system design processes, and
    ments

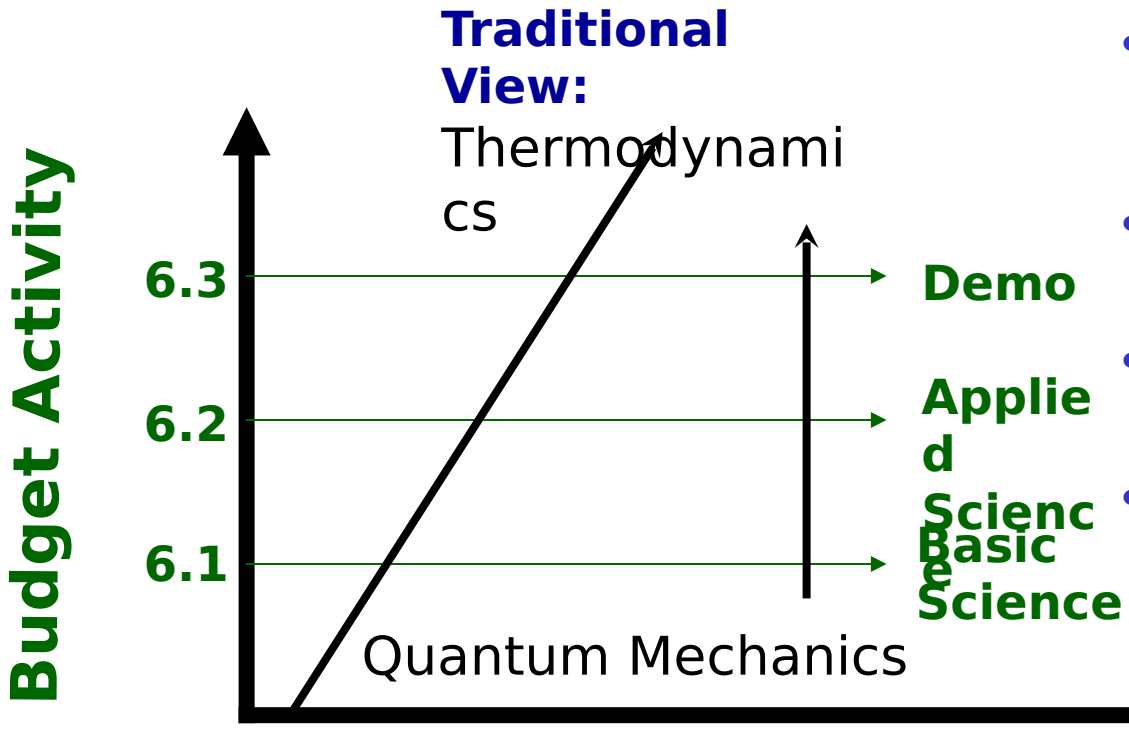


MUST Be Physics Based

Engineering Science Cycle

Traditional View and Funding the Navy Has No Control Over

Non-Linear & Discontinuous Process

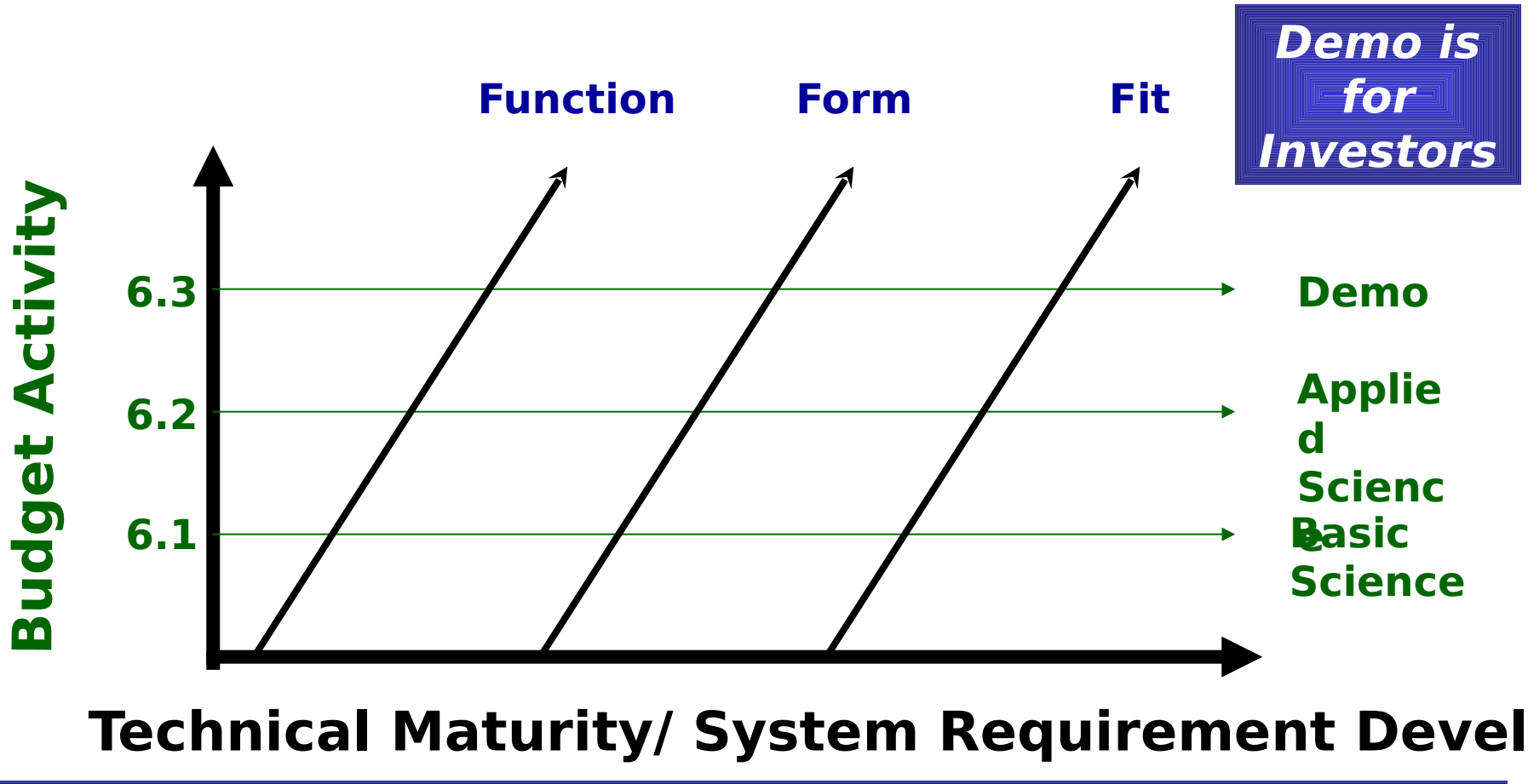


Holes in the development path:

- **No specification** funding – no military standards, must use commercial standards and best practices.
- No Funding for **Product Development** -- reliability assertions, warranties, component characterizations
- **No commercial** long term **S&T investments** in power electronics.
- **Expertise and manufacturing** mostly off-shore.
- **Integration and high volume production require a global market**

Engineering Science Cycle

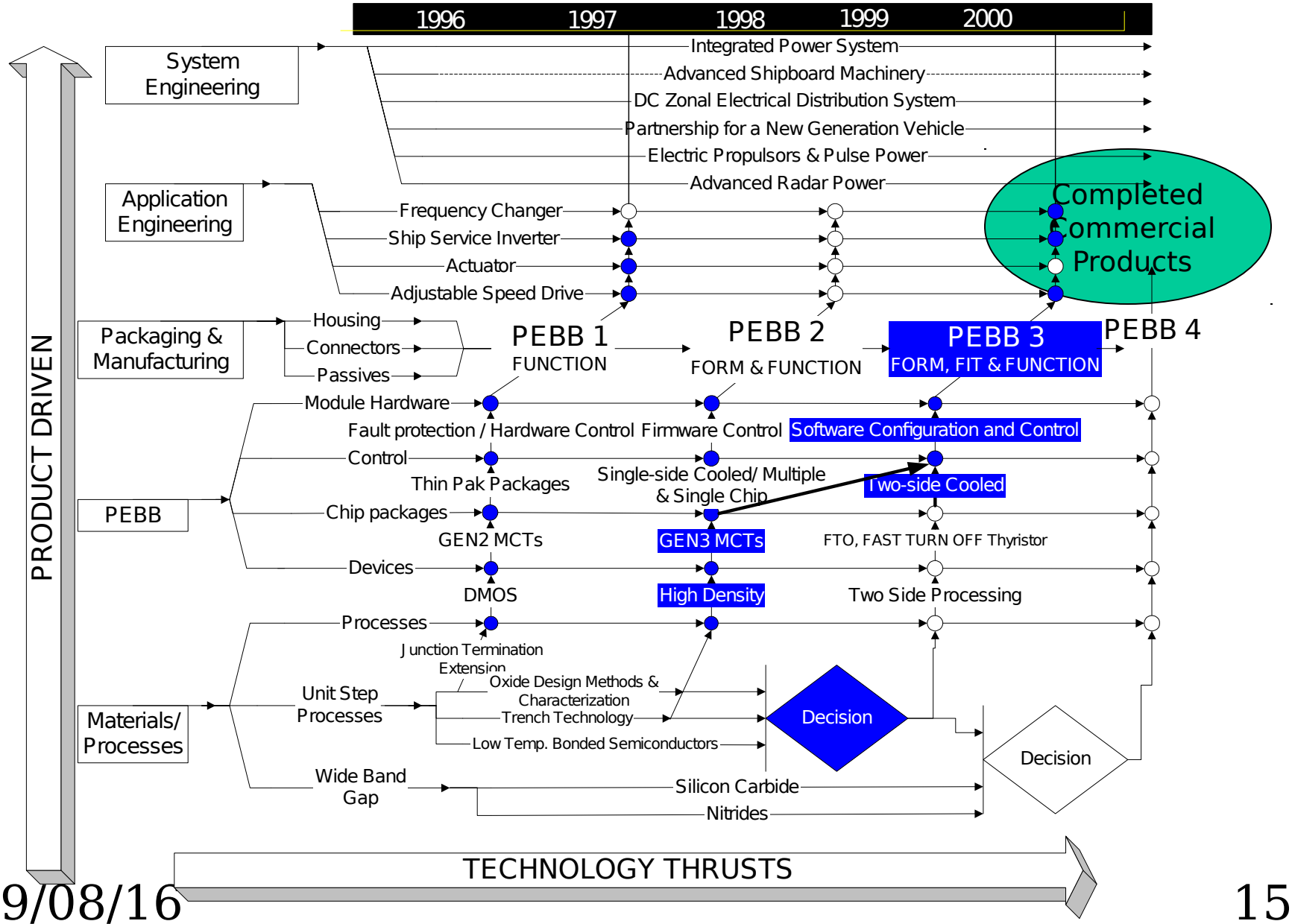
with Concurrent Engineering to Compel Industry to Invest



New Basic and Applied S&T Concepts for Electrical Power Necessitated by the introduction of non-liner, discontinuous, i.e. power electronics

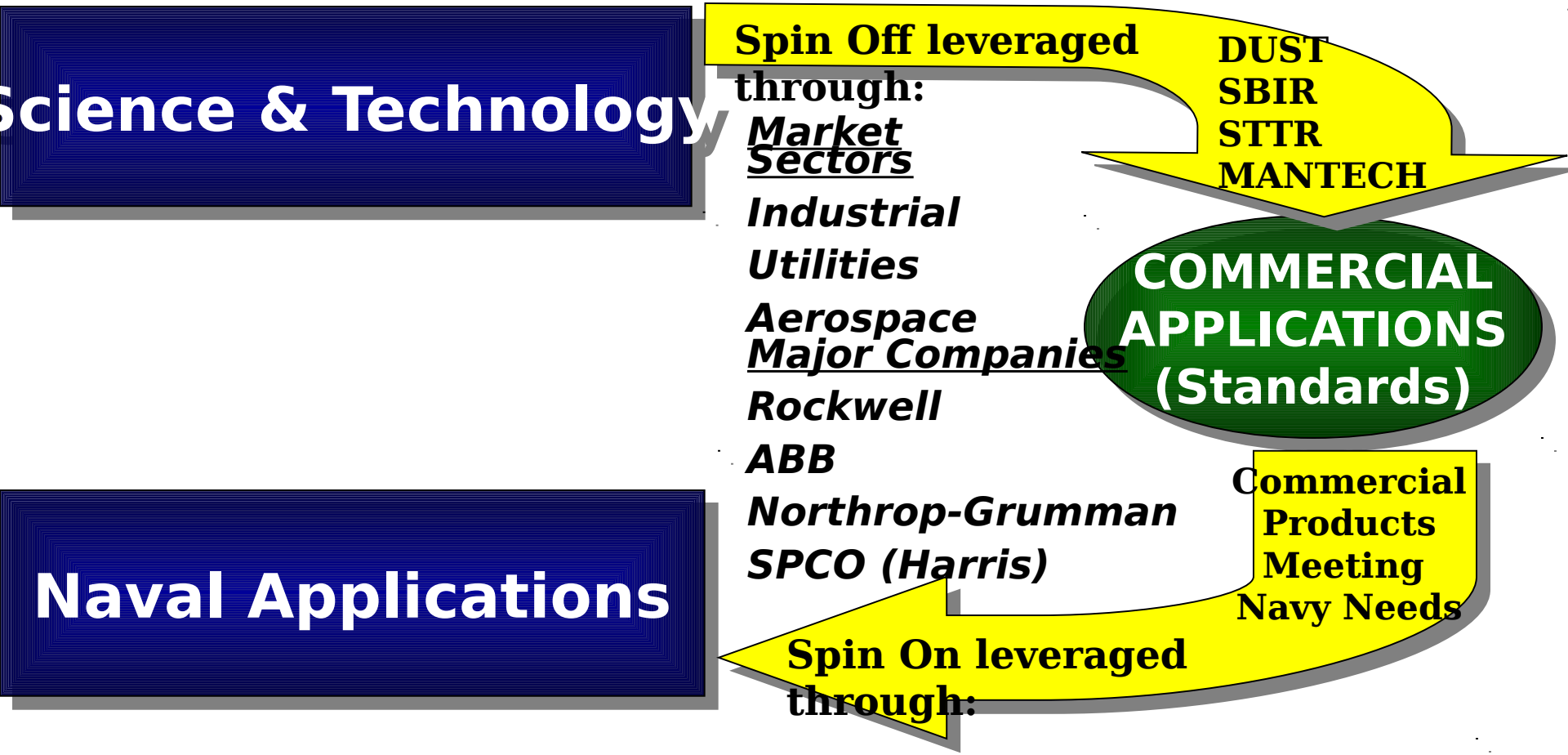
Advanced Electric Power Systems Thrust

Spider diagram showing the matrix of critical paths in the PEBB program



Advanced Electric Power Systems Thrust

PEBB: A Successful S&T/ Industry Partnership Model

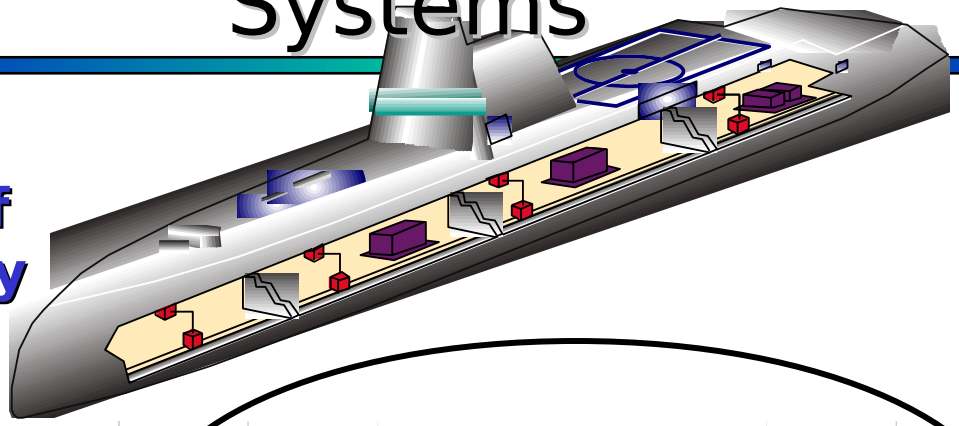


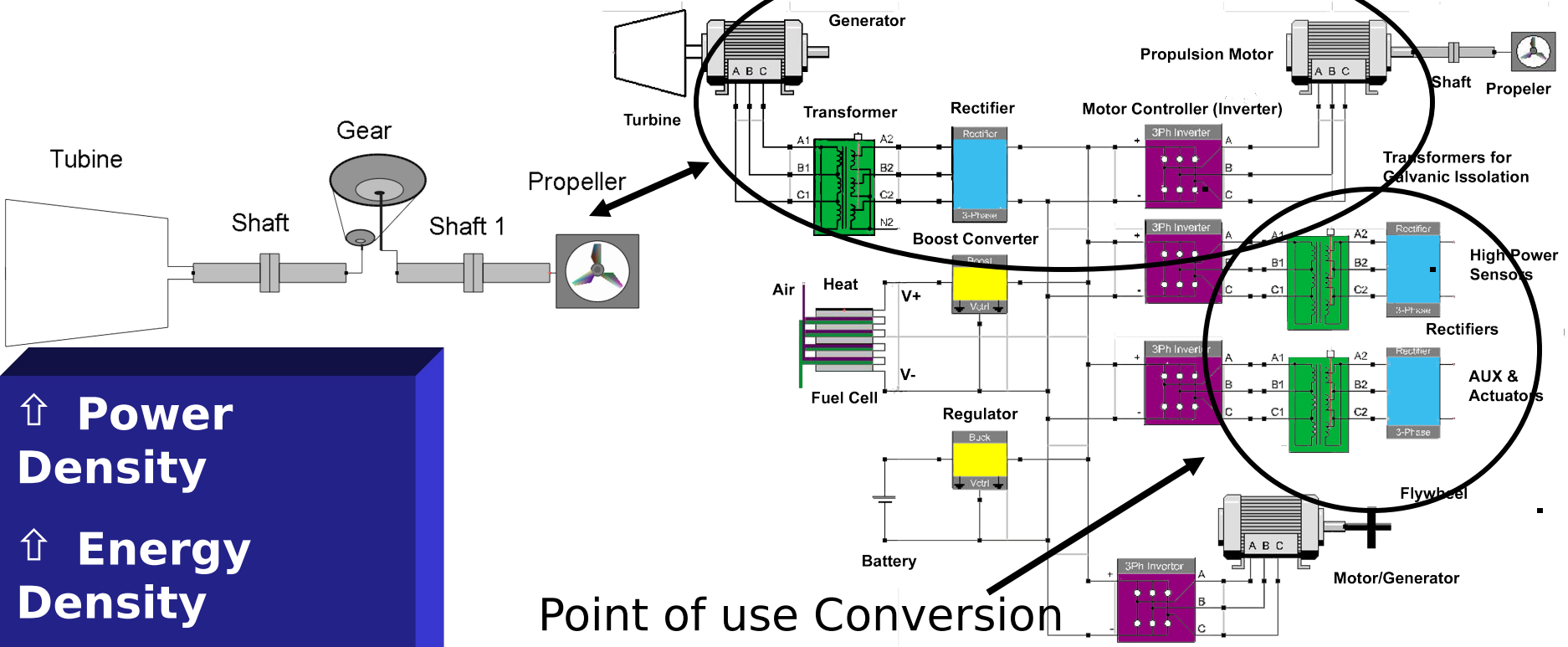
"Science & Technology working with industry

Advanced Electrical Power Systems

Advanced Electric Power Systems Thrust

Electrical power systems are made of many complex energy conversion machines





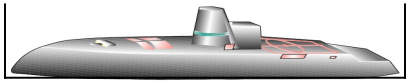
- ⇧ **Power Density**
- ⇧ **Energy Density**
- ⇧ **System Efficiency**

A Mechanical Propulsion System Is A Shaft and A Set Of

Advanced Electric Power Thrust

Future Electrical Power System Requirements

856 ft.



221 ft.

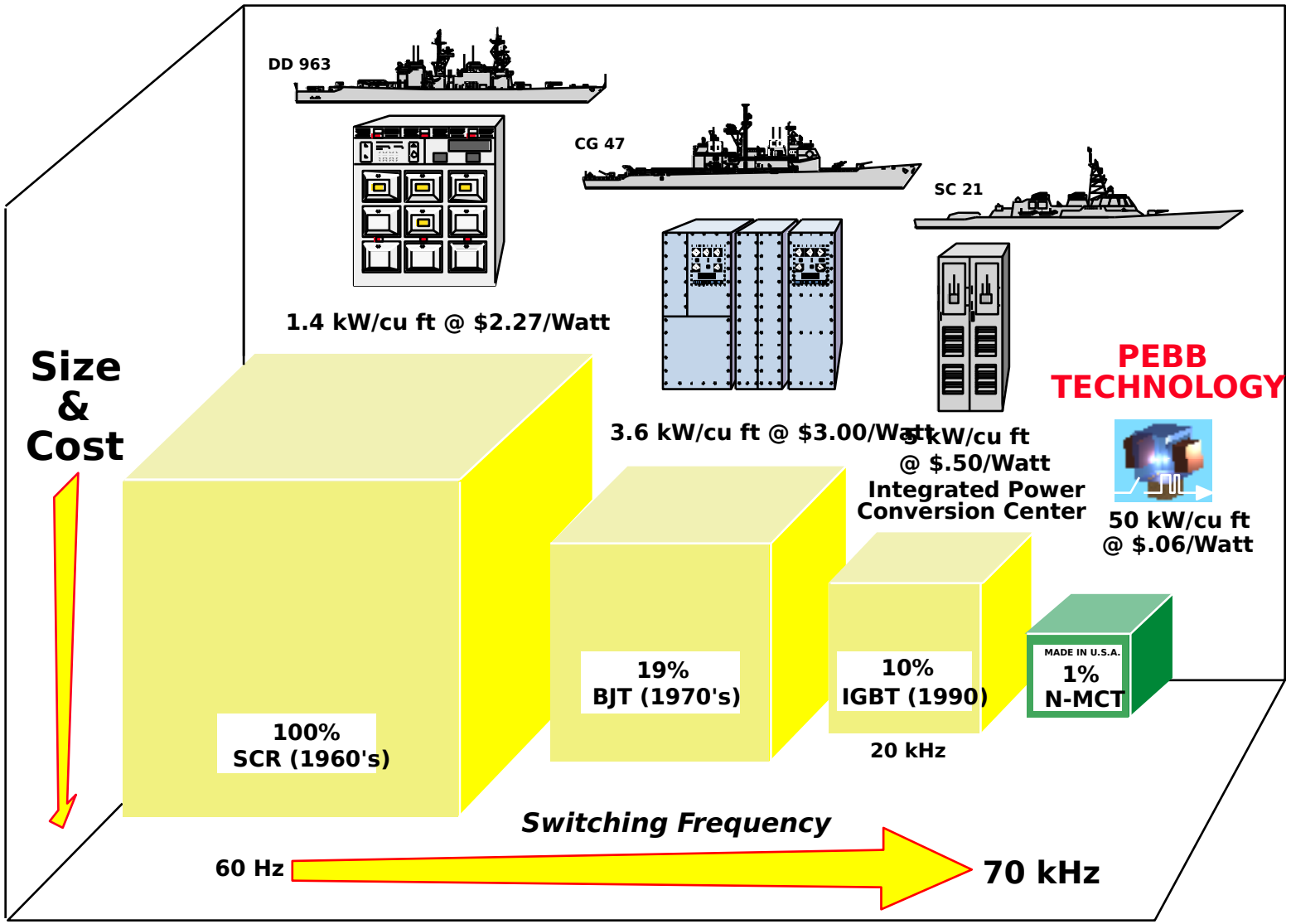
An Electric Navy Ship = 10x Cruise Ship Power Density

With pulse power, An Electric Warship = 20x Cruise Ship Power Density

Metrics	Elation Cruise Liner	Navy Littoral Combatant
Length, max: ft. Breadth, DWL: ft . Draught, DWL: ft.	856 103 26	221 22 7.2
Displacement: LT	~40,000	~2,000
Total Propulsion & Service Power Output: kW	47,520 with Azipod	~15,000→ 20,000
Specific Power Output: kW/LT	1.19	~7.5→10

Advanced Electric
Power Systems
Thrust

SHIPBOARD POWER SUPPLIES



Must Establish State-of-the-Art Power Electronic Baseline Metrics

- Advanced Electrical Power Systems -
New Technology Drivers

- ⇧ **Power Density**
- ⇧ **Energy Density**
- ⇧ **System Efficiency**
- ⇧ **Control**

- ⇩ **Number of Phase Legs**
- ⇧ **Reconfiguration**
- ⇧ **Voltage**
- ⇧ **Current**
- ⇧ **Frequency**

Source Voltage, rms Line-Line (volt)	Estimated Device Blocking Voltage (volt)	Notes
13800	40000	Many circuits are needed --parallel, series, and steps
4160	12000	Emerging solid-state solutions
440	1300	Solid-state solutions available
115	350	

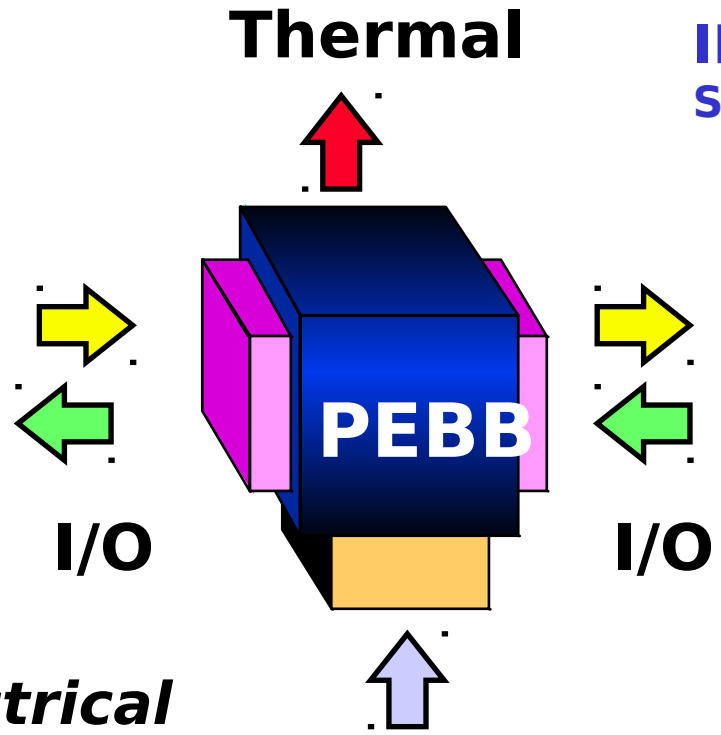
- Pulse forming networks require charging circuits ranging from **10kV to 40kV**.
- Pulse forming discharge circuits can require up to **100kV switching**.
- Modulator circuits require **10kV to 50kV** for input voltages and output voltages ranging from **50kV to 1MV**.

A 210 MW, 3phase 4160v, system would take ~ 90 Phase-Legs in today's

Advanced Electric Power Systems Thrust

Step 1 PEBB* -- A Simple Set of Blocks for Power System Development

*** PEBB defined by IEEE (Power Engineering Society)**



Senses what they are plugged into...

Senses what is plugged into them...

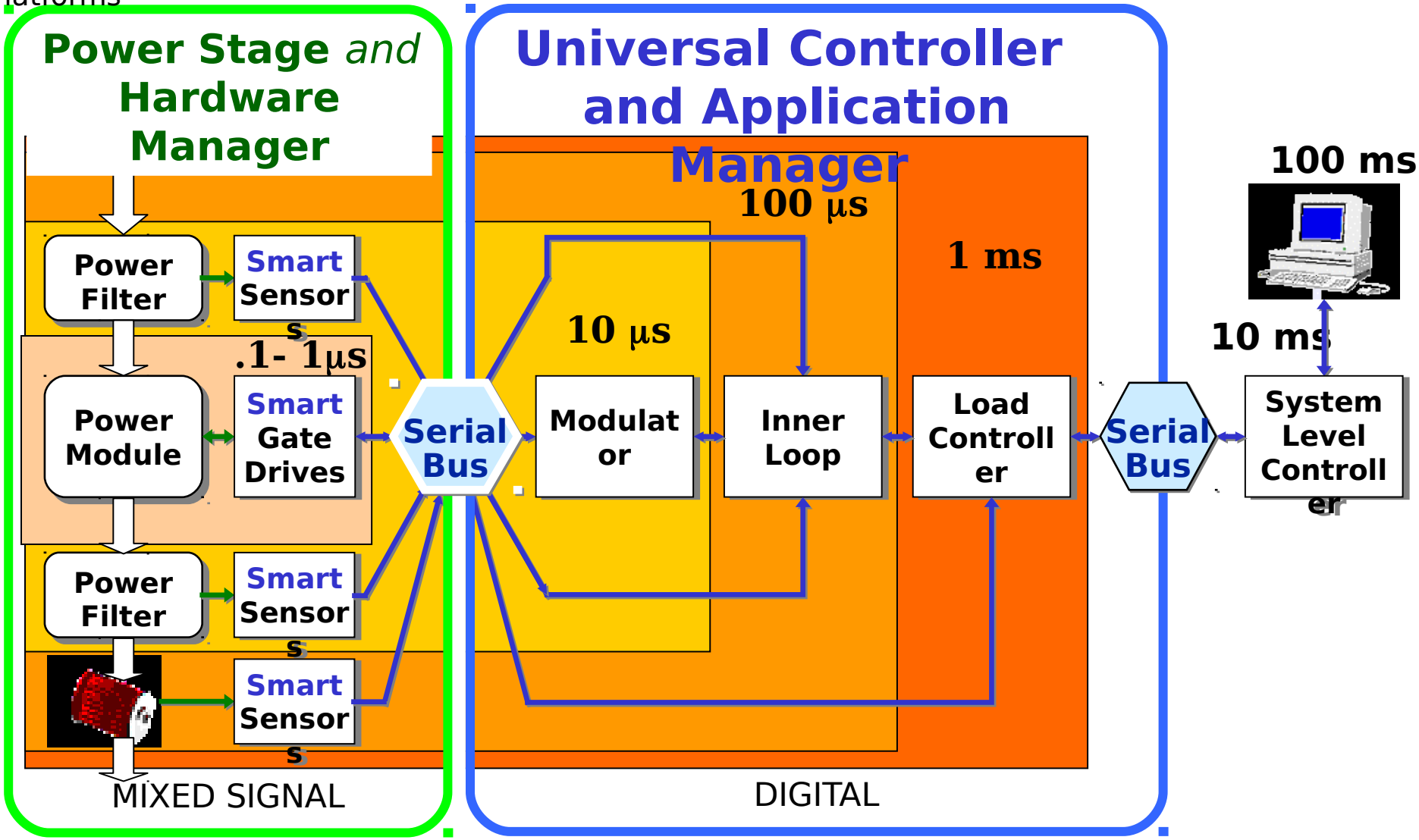
Makes the electrical conversion needed via software programming

Functions In Softwa
Inverter
Breakers
Frequency Converte
Motor Controller
Power Supply
Actuator Controller

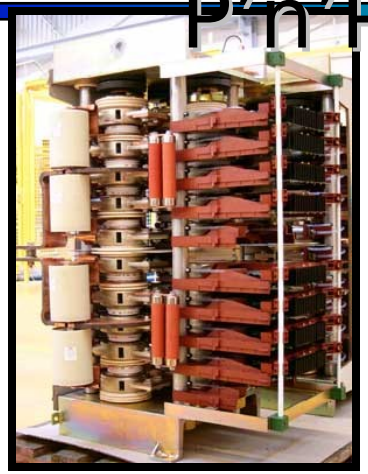
Like a child's set of blocks

Step 2. Universal Controller Architecture (CPES & NSWC)

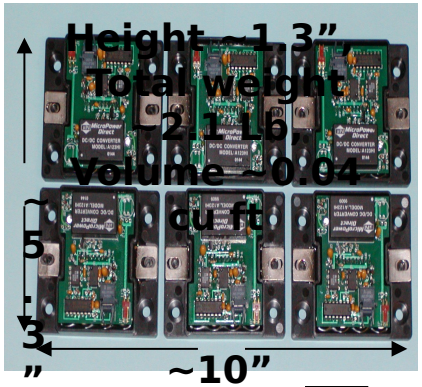
Surface & Subsurface Platforms



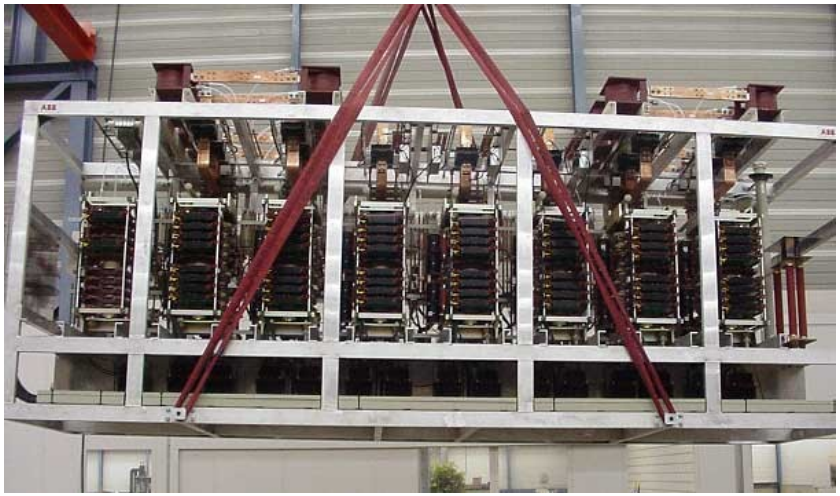
Step Three -- Technology Independent P'n'P (Plug and Play)



- Create Military PnP PEBB based on Flat-Pak
- Design multi-chip version to fit Military PnP PEBB created
- Demonstrate interchangeability



Military PnP PEBB

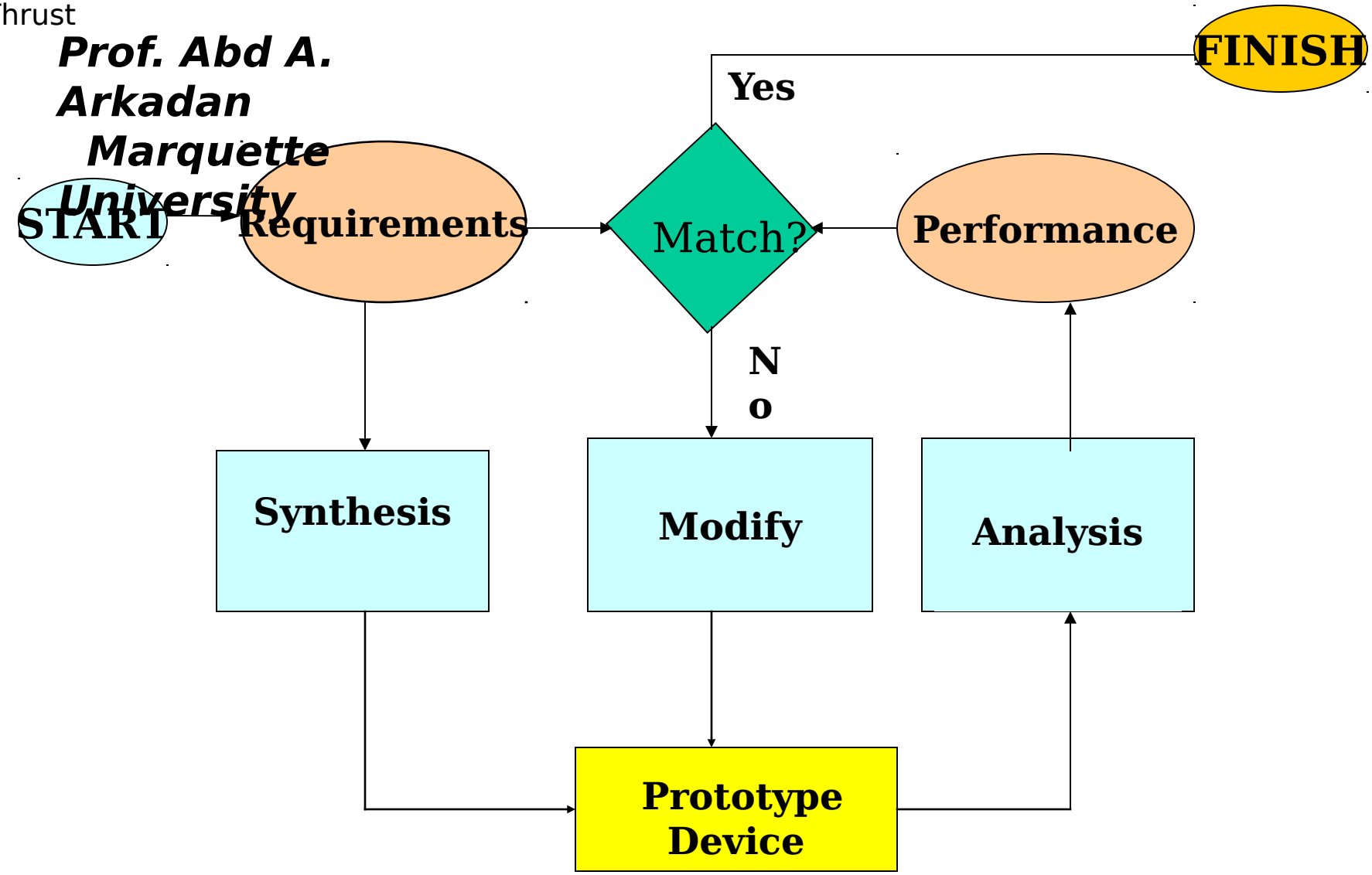


Step Four -- Shipboard Backplane (Thermal, Electrical, and Mechanical)

- Integrated Bulkhead
  - Bus duct
  - Integrated normal and alternate cooling
  - Bus feed through
  - High voltage construction
  - High Impact shock
  - Increased packaging efficency

The Design Process

Prof. Abd A. Arkadan
Marquette University



The Design Process

Direct Problem

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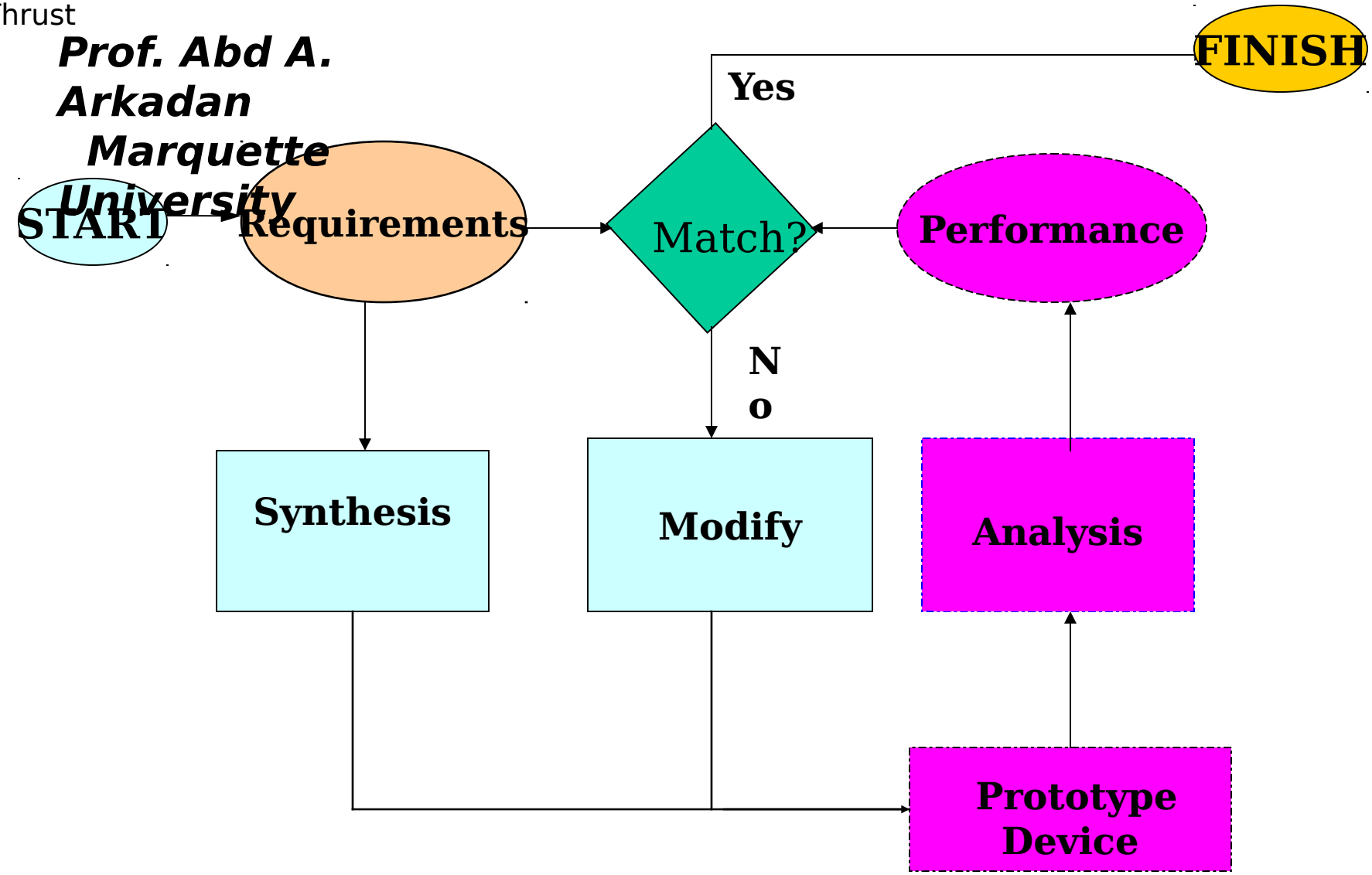

The Design Process

Inverse Problem

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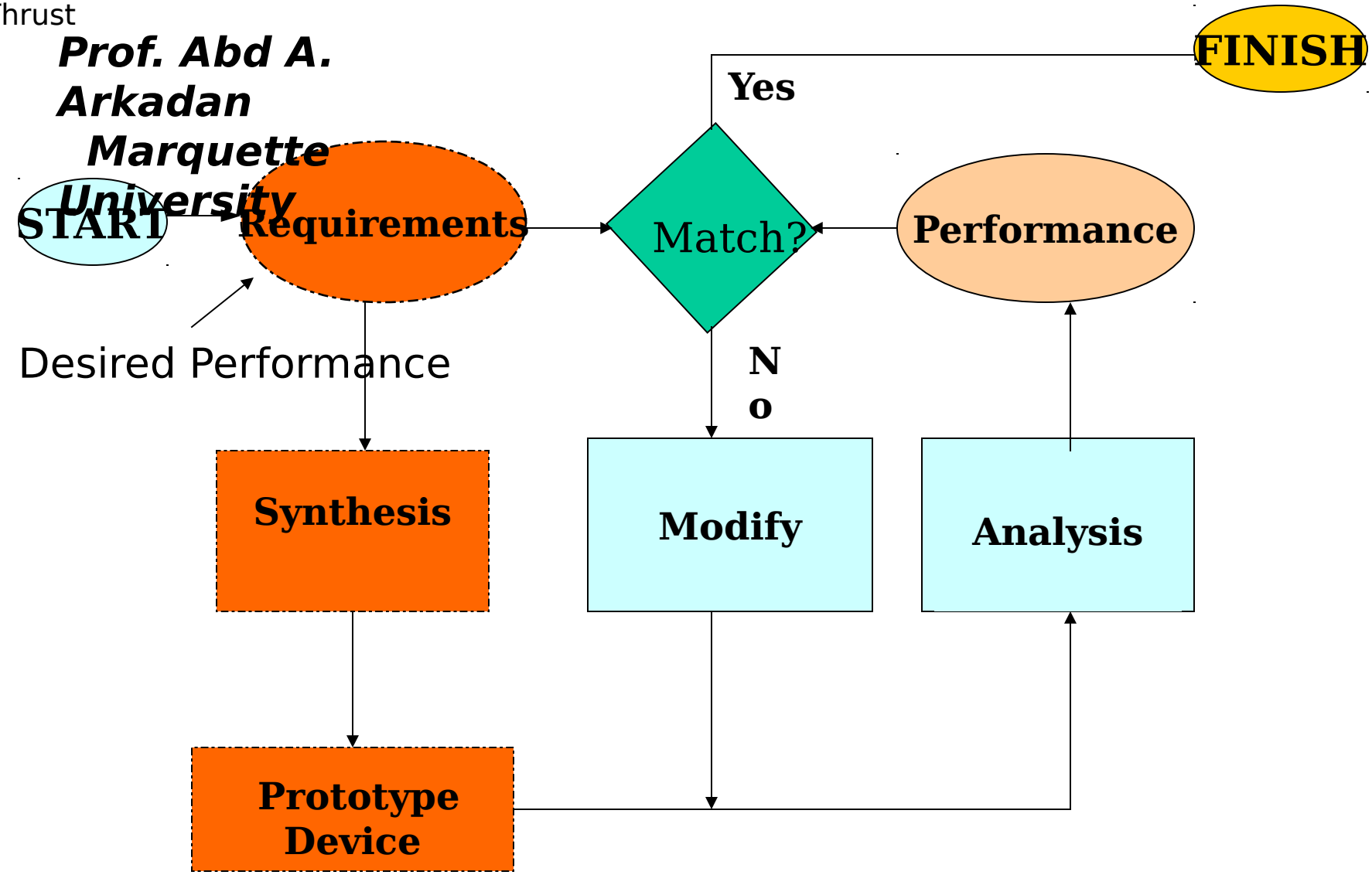


Characteristics of Inverse & Direct Problems

Prof. Abd A. Arkadan
Marquette University

Direct problem:

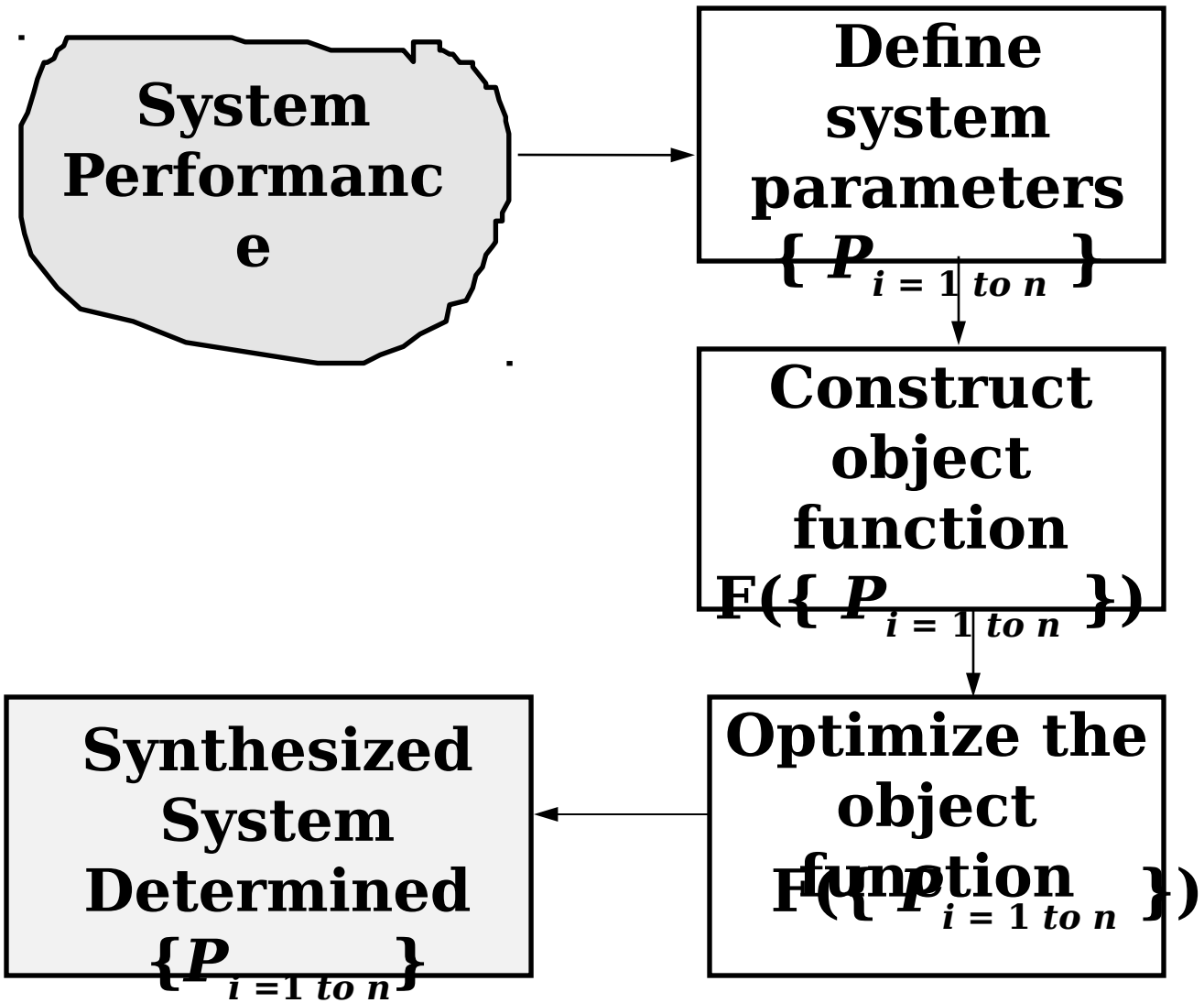
It is well posed

- existence : a solution exists
- unique : one solution
- stability : solution depends continuously on data

Inverse Problem:

- usually less is known about the problem
- ill posed

Solution Steps in Inverse Problem Methodology



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